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NASA Contractor Report 3778

**NASA/MSFC Ground-Based Doppler  
Lidar Nocturnal Boundary Layer  
Experiment (NOBLEX)**

**G. D. Emmitt**

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## NASA Contractor Report 3778

# NASA/MSFC Ground-Based Doppler Lidar Nocturnal Boundary Layer Experiment (NOBLEX)

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Prepared for  
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NASA/MSFC GROUND-BASED DOPPLER LIDAR

NOCTURNAL BOUNDARY LAYER EXPERIMENT (NOBLEX)

OBJECTIVE: To explore the capabilities of NASA/MSFC's ground-base 10.6  $\mu\text{m}$  pulsed Doppler lidar in providing flow visualization in a stable planetary boundary layer.

METHODOLOGY: Use low angle (1-10 $^{\circ}$ ) VAD scans during the period 2000 - 2300 LST. Examine the scans for persistent flow features that may be forced topographically.

RESULTS: Detection of the evolution of a channelled flow that was -4 times deeper than the responsible topographical structure.

## INTRODUCTION

As part of its ground-based testing and application, the NASA/MSFC's 10.6  $\mu\text{m}$   $\text{CO}_2$  pulsed Doppler Lidar Velocimeter (DLV), (Figure 1) was taken to Denver, Colorado in the summer of 1982 as part of NASA's participation in the JAWS (Joint Airport Weather Studies) Program. The primary objective of JAWS was to examine the generation, maintenance and decay of intense subcloud layer outflows from cumulus convection - density currents having the potential to significantly alter an aircraft's flight path. To achieve this objective, many observational tools were employed - Doppler radars, aircraft, surface networks, microwave sounders, lidars, etc. The lidars (NOAA and NASA) were used to provide wind measurements in the cloud-free and precipitation free regions when insufficient backscatter was available for the co-located Doppler radars.

To take advantage of the complimentary and supplementary data being gathered within the range (~12 km) of the DLV, several experiments not dealing with cloud outflows were designed and executed during the JAWS field program. One of these ancillary studies involved the low-angle scanning of the NASA DLV during the onset of the nocturnal boundary layer (NOBLEX - Nocturnal Boundary Layer Experiment). The period just around sunset is a time when the boundary layer is transitioning from thermally unstable mixing to stable mixing. Differential radiational cooling on the slopes of valleys and mountains can lead to the generation of density currents which flow downslope and may because of reduced mixing maintain their lateral and vertical identity for some distance into unbounded regions of the boundary layer.

Depending upon the responsible topographical structures, nocturnal drainage flows can have dimensions that make obtaining representative measurements with conventional systems (e.g. towers, pibals, tethered balloons, aircraft) difficult, if not impossible. The NASA DLV has a cylindrical sample volume of length 330 m and radius 15 cm and a hemispherical range of 10-15 km to achieve better flow descriptions was obvious. The case study presented here is meant to demonstrate the capabilities of the DLV to provide detailed flow visualizations for the very specific situation of a stabilizing planetary boundary layer (PBL) - a situation that remains a challenge to the numerical modelling of the complete diurnal cycle of PBL evolution.

## THE EXPERIMENT

### Location

The NASA/MSFC's DLV was located at the Denver Stapleton Airport (CP-4 on Figure 2). From the lidar scanner's vantage point, complete  $1^\circ$  elevation PPI were possible except for blockage between  $215^\circ$  and  $250^\circ$  by the radome of the NCAR radar. A visual inspection of the surrounding terrain within 20 km of CP-4 gave the impression of being quite flat with minor relief on the order of 20-50 meters. In the distance to the west and southwest were the Rocky Mountains while in all other directions it appeared to be relatively flat. Examination of topographic maps confirmed this general impression, however, to the south and southeast the surface sloped gradually upward to a point 50 km away that was nearly 500 m above the lidar site. For a nocturnal boundary layer this is not an insignificant slope as will be illustrated by the following case study.

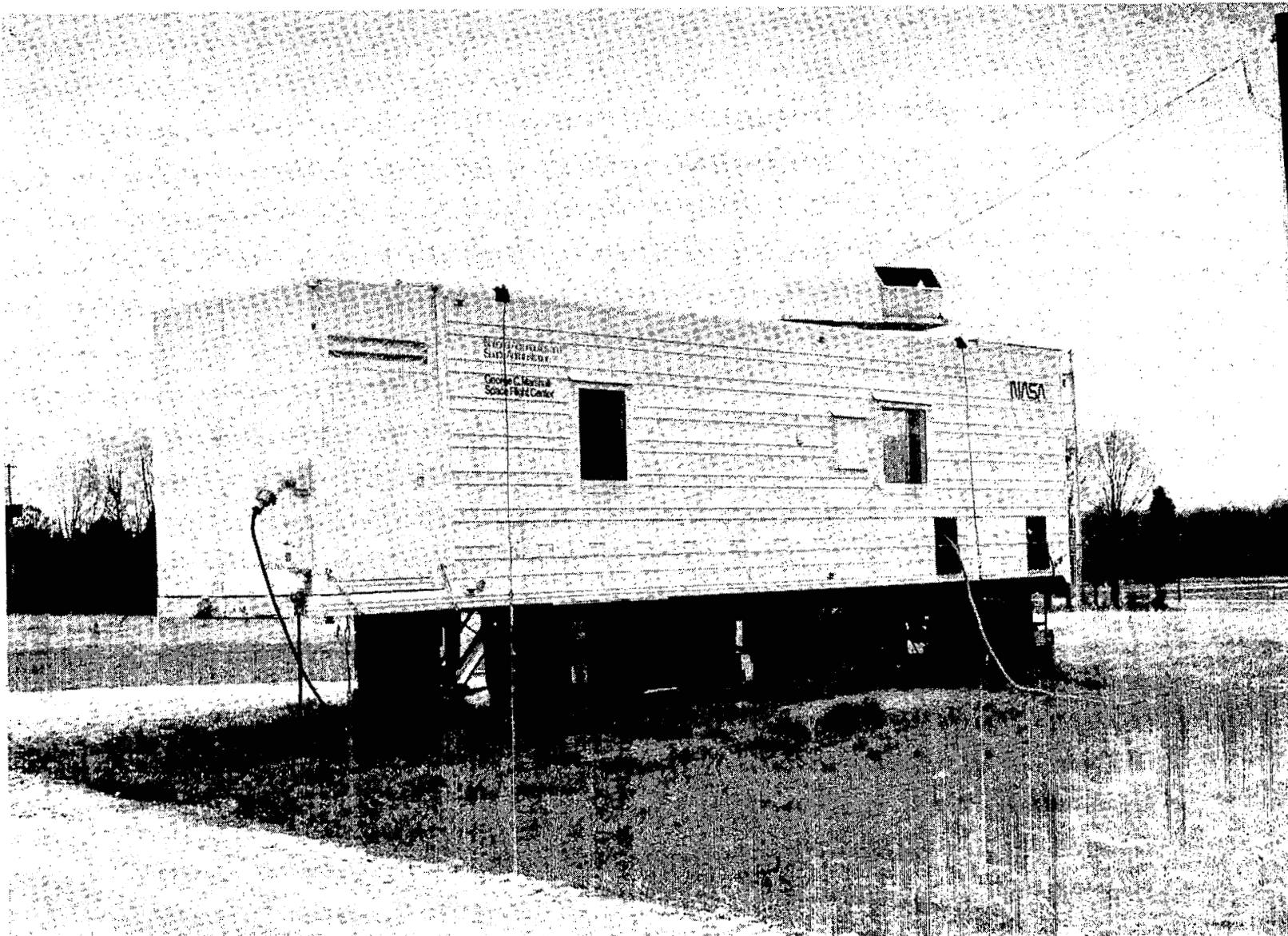


FIGURE 1. Trailer that houses the complete NASA/MSFC's 10.6  $\mu\text{m}$   $\text{CO}_2$  pulsed Doppler Lidar Velocimeter. The system includes the laser; optics to guide the beam to the hemispherical scanner; computer to control the scanner, a data system to record, analyze and display the laser sensed wind field data.

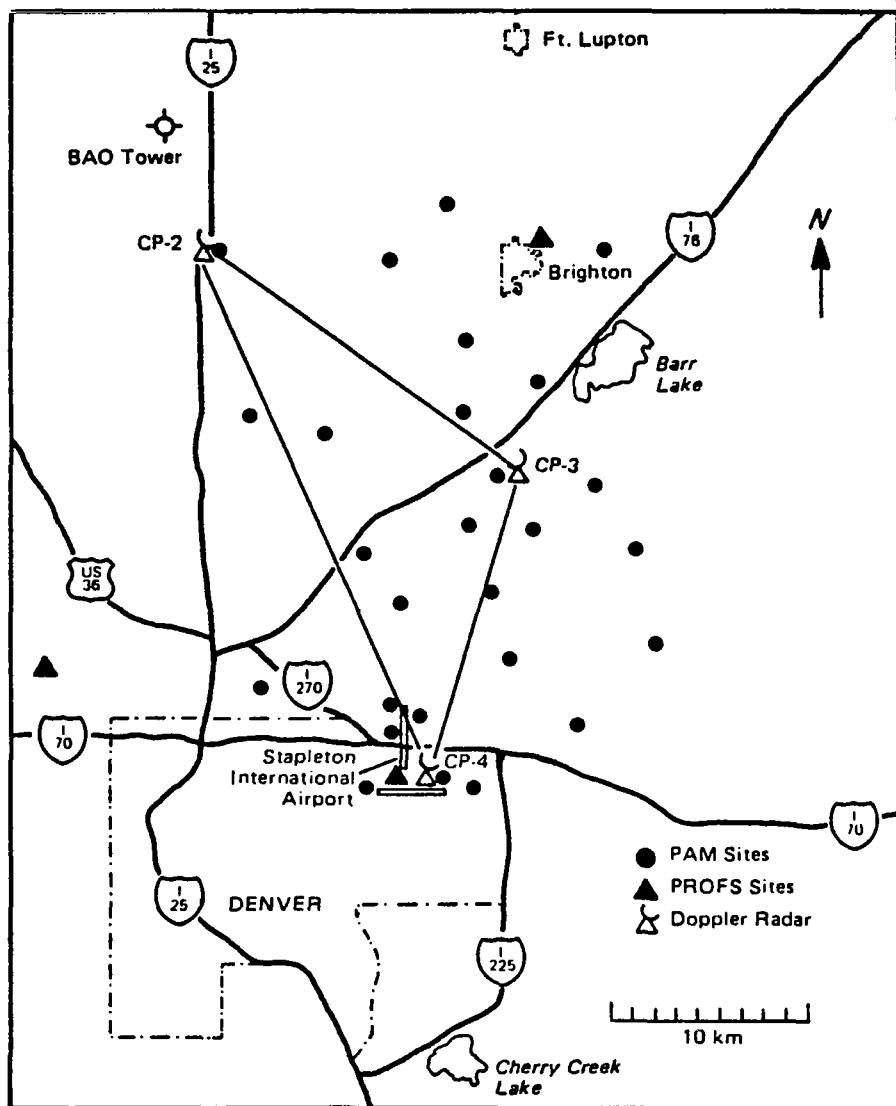


FIGURE 2. JAWS observation network with the location of the NASA/MSFC's DLV noted by an \*.

## Meteorology

During the afternoon of 31 July 1982 there was a weak but persistent NNE PBL flow of  $2-4 \text{ ms}^{-1}$ . Surface temperatures were between  $29^\circ\text{C}$  and  $30^\circ\text{C}$  with dewpoints varying from  $4^\circ\text{C}$  to  $7^\circ\text{C}$  (Figure 3). Above the surface the winds backed with height to  $5 \text{ ms}^{-1}$  from  $270^\circ$  at 2000 m AGL. Beginning around 1900 MST a SSE PBL flow was detected by the eastern most PAM stations (Figure 4a). An hour later (Figure 4b) the western edge of the southerly current had moved well into the PAM array and had just reached the lidar site. By 2100 (Figure 5a) all the PAM stations were detecting the southerly flow which lasted until at least midnight (Figure 6b). The time series of the surface measurements made nearest the lidar van are presented in Figures 7 and 8. The onset of net radiational cooling can be seen around 1800 MST. At 1945 the sharp wind direction change was accompanied by rising dewpoint and a slight increase in wind speed. The completed shift to a southerly flow occurred at 2230 MST. It was during the time period (2000-2300 MST) that the NASA/MSFC's DLV was being operated in a low elevation angle ( $1^\circ$ - $10^\circ$ ) scan mode.

## RESULTS

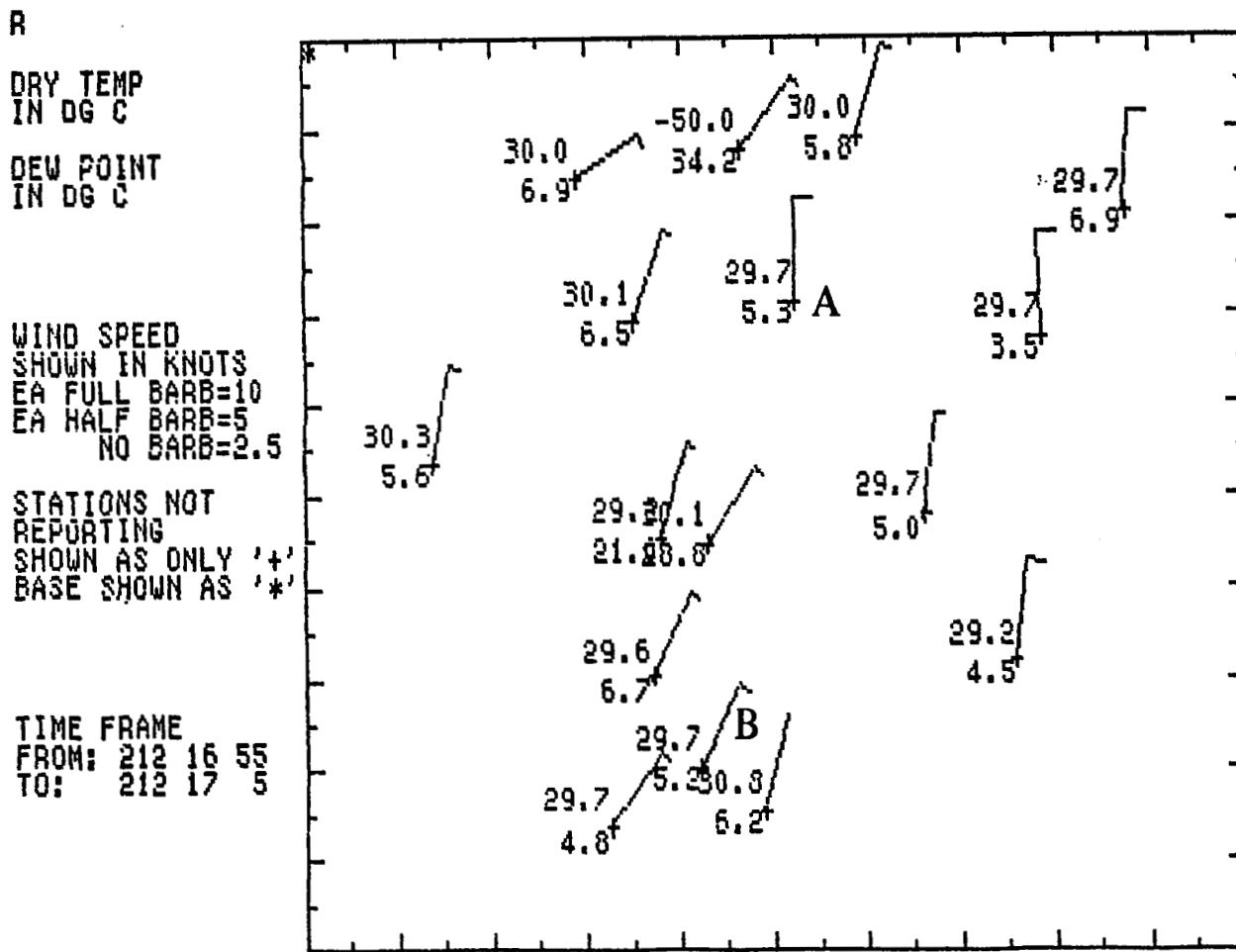
Before presenting the lidar data it must be mentioned that during JAWS the DLV was operated without the benefit of a real time display of the velocity information. The lidar was therefore scanned over a rather large volume to insure the detection of any persistent flow features that may exist. With a real time display, a much more complete documentation of a specific flow structure would have been possible. It was not until post JAWS processing of the data that it was discovered that an interesting flow phenomena had been sampled.

Throughout the presentation of lidar data the following system parameters are kept constant:

pulse width	$2 \mu\text{s}$ (-330 meters)
pulse repetition	110 Hz
pulse integrations	50
slew rate	$6^\circ \text{ s}^{-1}$
range gate	-8000 meters

It must also be pointed out that the height of the lidar beam above the ground varied with azimuth. As is illustrated in Figure 9, the amplitude of the topography trace at 8 km range is about 120 meters. This means that at  $2^\circ$  scan elevation the beam at 8 km will vary from -200 m to -320 m AGL.

At 2042 MST, the lidar detected an unbalanced flow at  $2^\circ$  elevation (Figure 10). Neglecting the effects of the sloping topography as shown in Figure 9 the implied convergence is approximately  $5 \times 10^{-4} \text{ s}^{-1}$ . The general conclusion is that there was a density current approaching the lidar site from the south but had not yet passed completely through the scan domain (8 km radius). It was not until 2130 MST that a series of low angle scans between  $2^\circ$  and  $8^\circ$  elevations provided a vertical cross section of the southerly flow feature (Figure 11). The high angle ( $8^\circ$ ) scan indicates a very weak flow near 1100 meters AGL. As the lidar scanned lower into the boundary layer a distinct jet-like feature was resolved. It had a ground speed of  $5-6 \text{ ms}^{-1}$ , width of 6-7 km and a depth of 700-800 meters. Its speed relative to the general PBL flow was  $2-3 \text{ ms}^{-1}$ .



**FIGURE 3.** Surface temperature, dewpoint and wind data from NCAR's Portable Automated Mesonet (PAM). Each tic mark around the border represents 1 km; the time is MST; the data shown are 10 minute averages centered on the hour; no reliable wind measurements are made at station labeled "A"; and the station nearest the MSFC's lidar van is labeled "B."

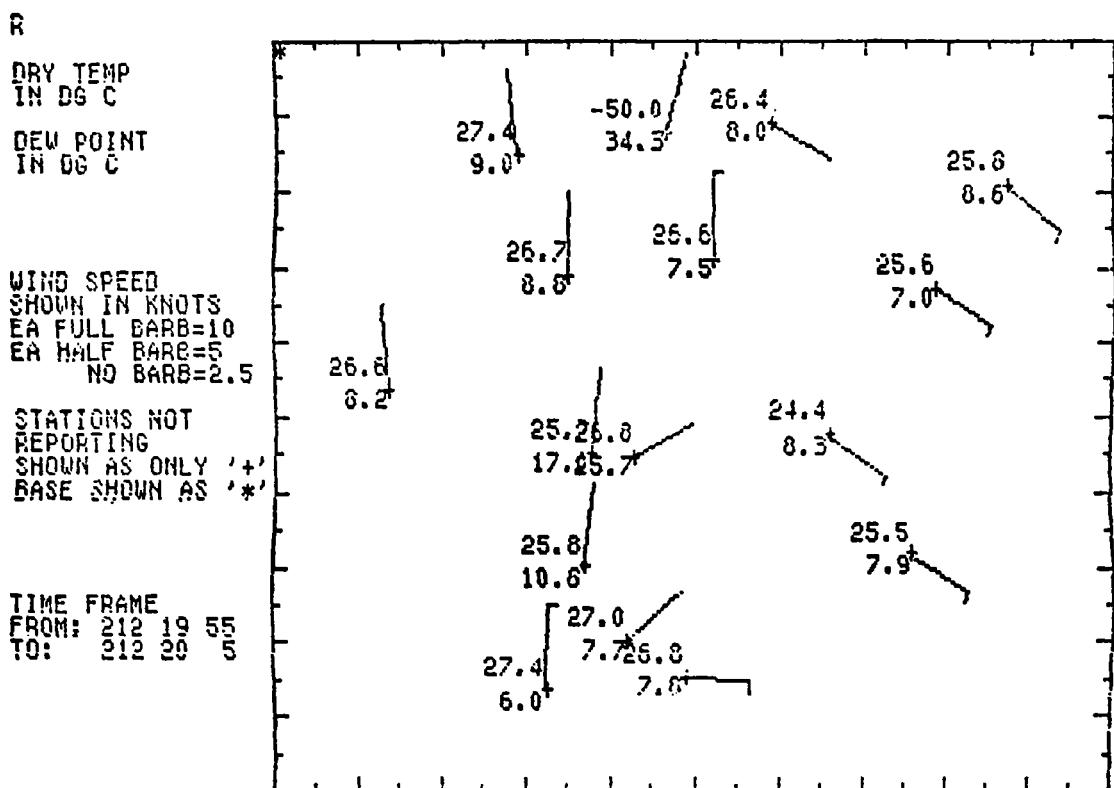
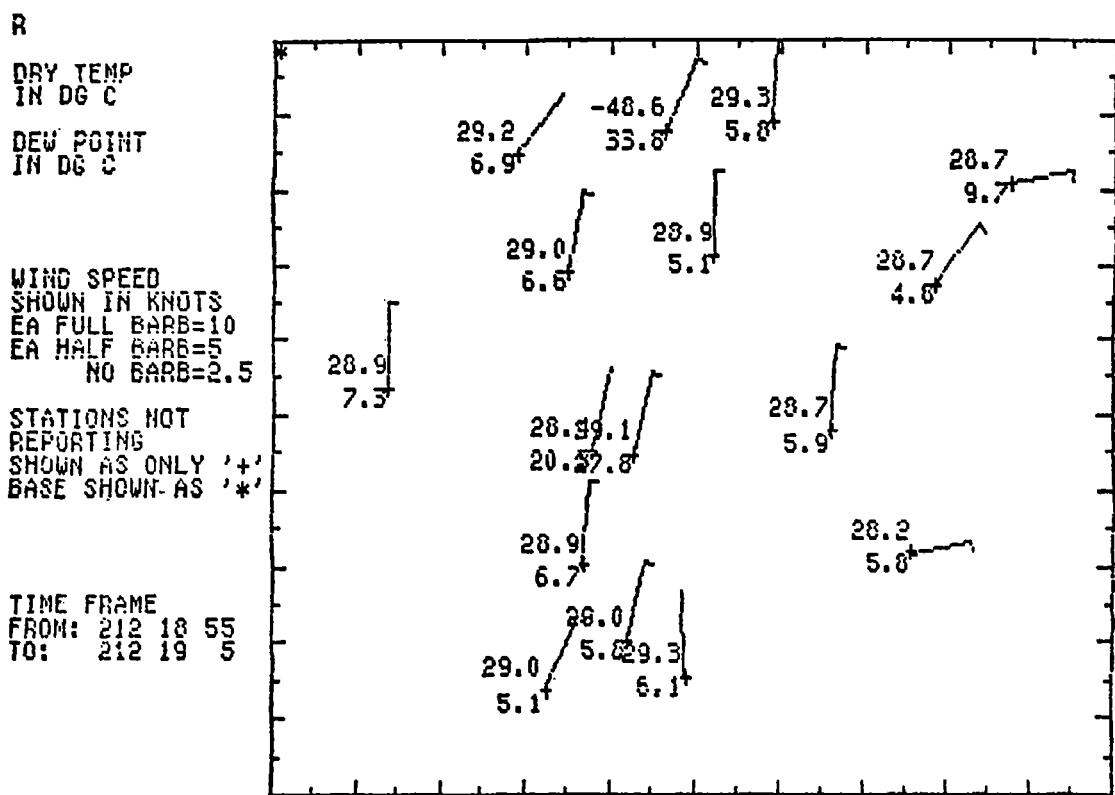


FIGURE 4. a. 1900 MST 31 July 1982 PAM data (see caption on Figure 3).  
b. 2000 MST 31 July 1982 PAM data (see caption on Figure 3).

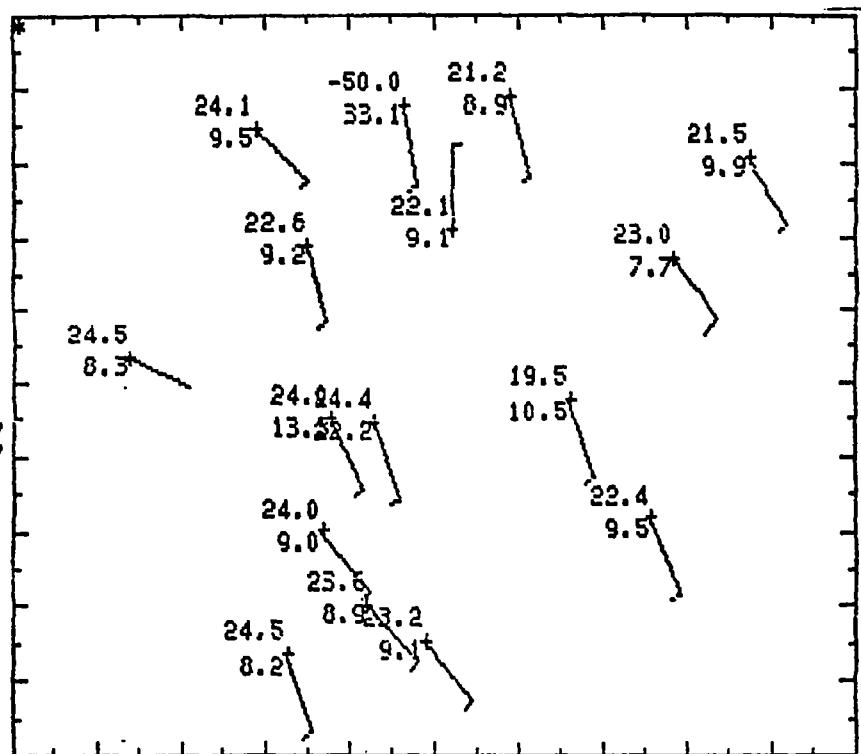
DRY TEMP  
IN DG C

DEW POINT  
IN DG C

WIND SPEED  
SHOWN IN KNOTS  
EA FULL BARB=10  
EA HALF BARB=5  
NO BARB=2.5

STATIONS NOT  
REPORTING  
SHOWN AS ONLY '+'  
BASE SHOWN AS '\*'

TIME FRAME  
FROM: 212 20 55  
TO: 212 21 5



R

DRY TEMP  
IN DG C

DEW POINT  
IN DG C

WIND SPEED  
SHOWN IN KNOTS  
EA FULL BARB=10  
EA HALF BARB=5  
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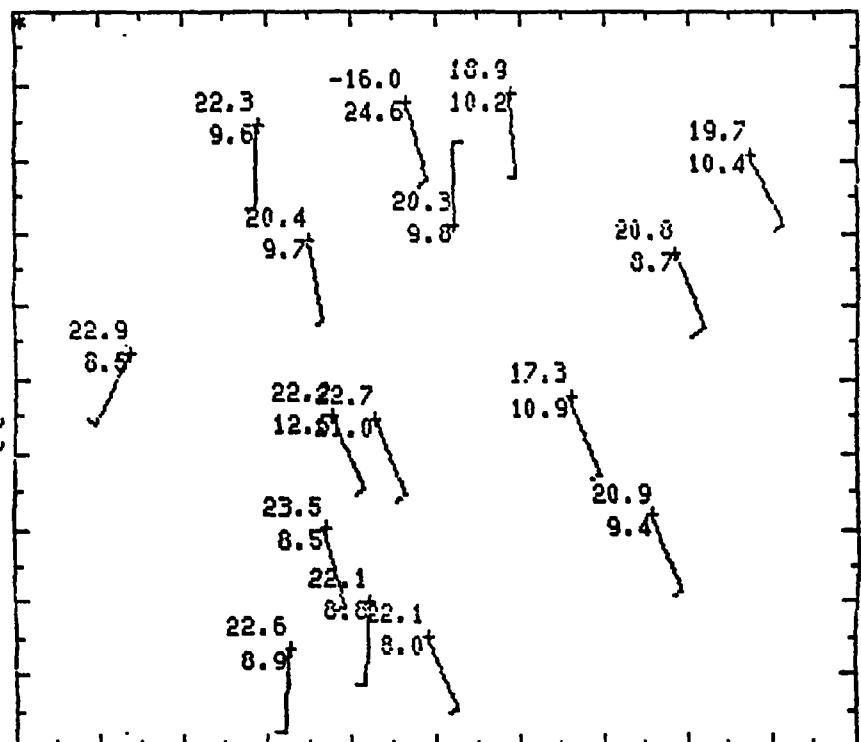


FIGURE 5. a. 2100 MST 31 July 1982 PAM data (see caption for Figure 3).  
b. 2200 MST 31 July 1982 PAM data (see caption for Figure 3).

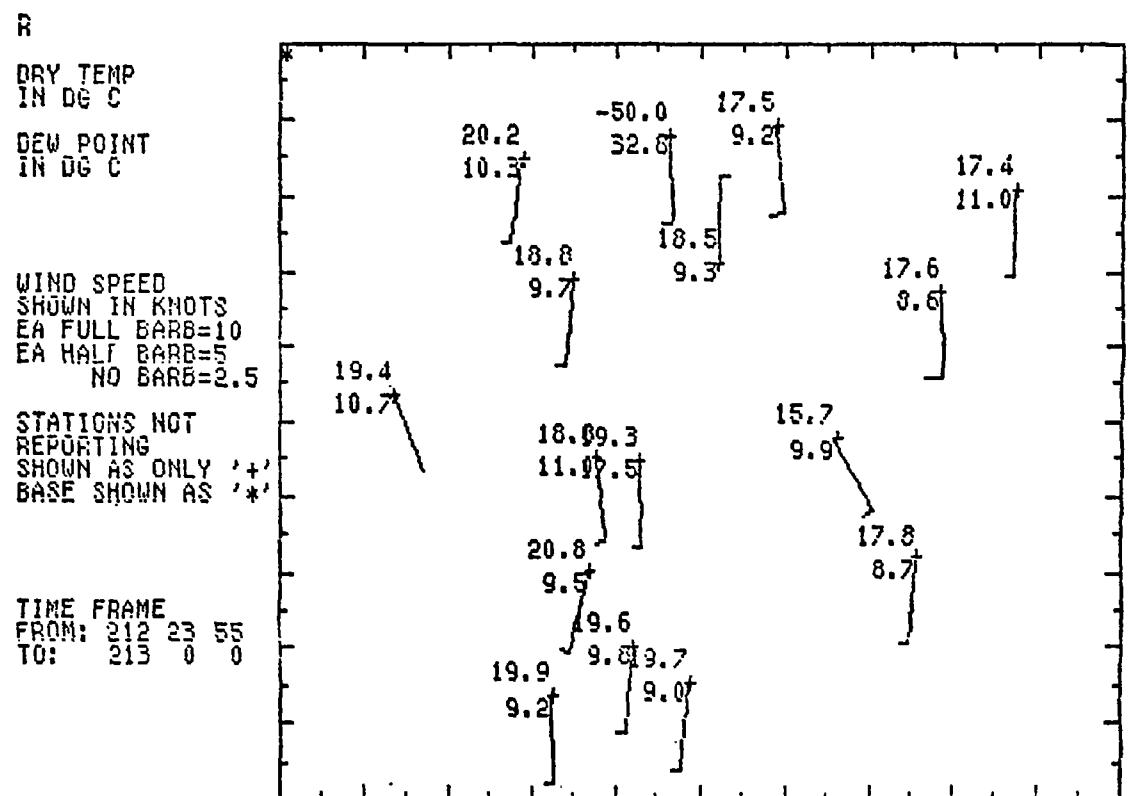
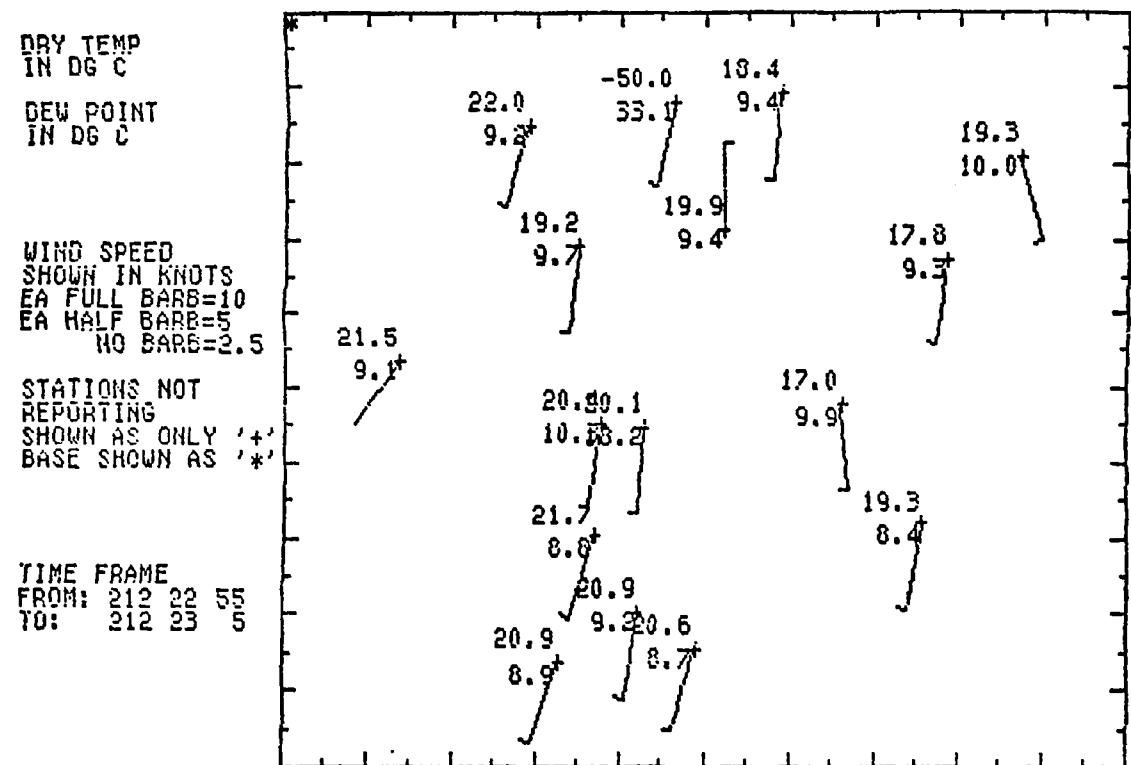


FIGURE 6. a.. 2300 MST 31 July 1982 PAM data (see caption for Figure 3).  
 b.. 0000 MST 1 August 1982 PAM data (see caption for Figure 3).

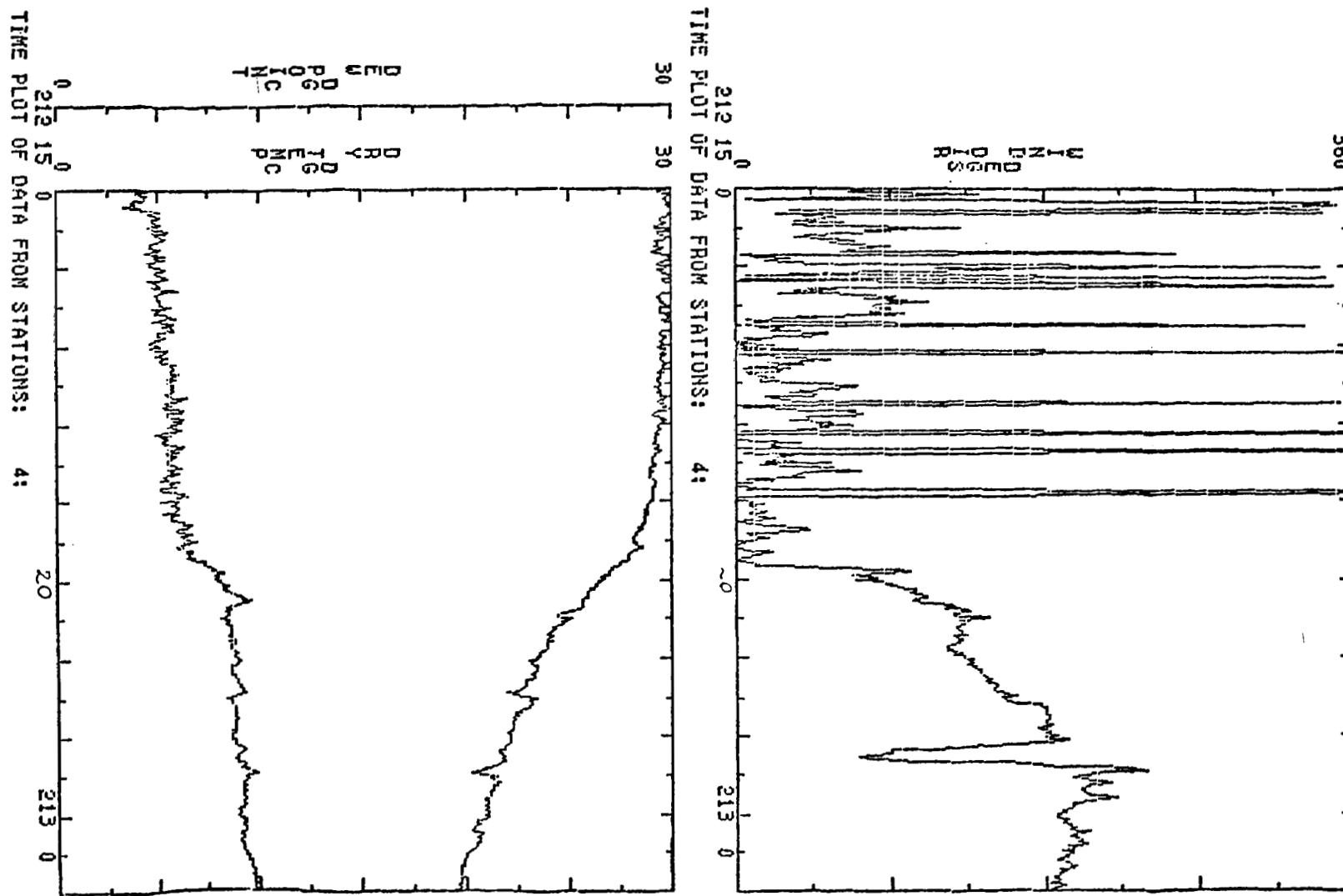


FIGURE 7. Surface data from 1500 MST 31 July 1982 to 0000 MST 1 August 1982 for PAM station number 4 which was within 1 km of the NASA/MSFC's lidar van. 2000 MST is labeled to denote start of lidar sampling for NOBLEX.

R

4

A

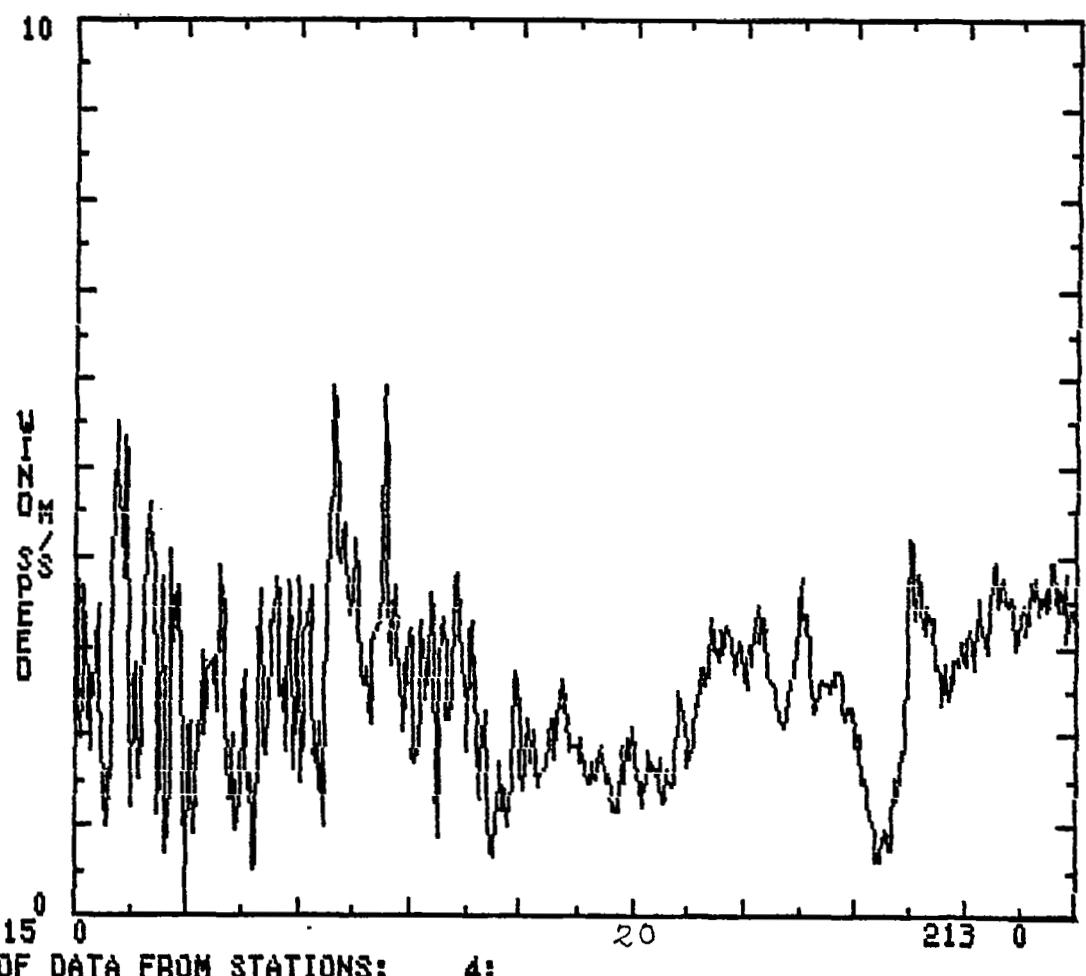


FIGURE 8. Same as for Figure 7 except wind speed is plotted.

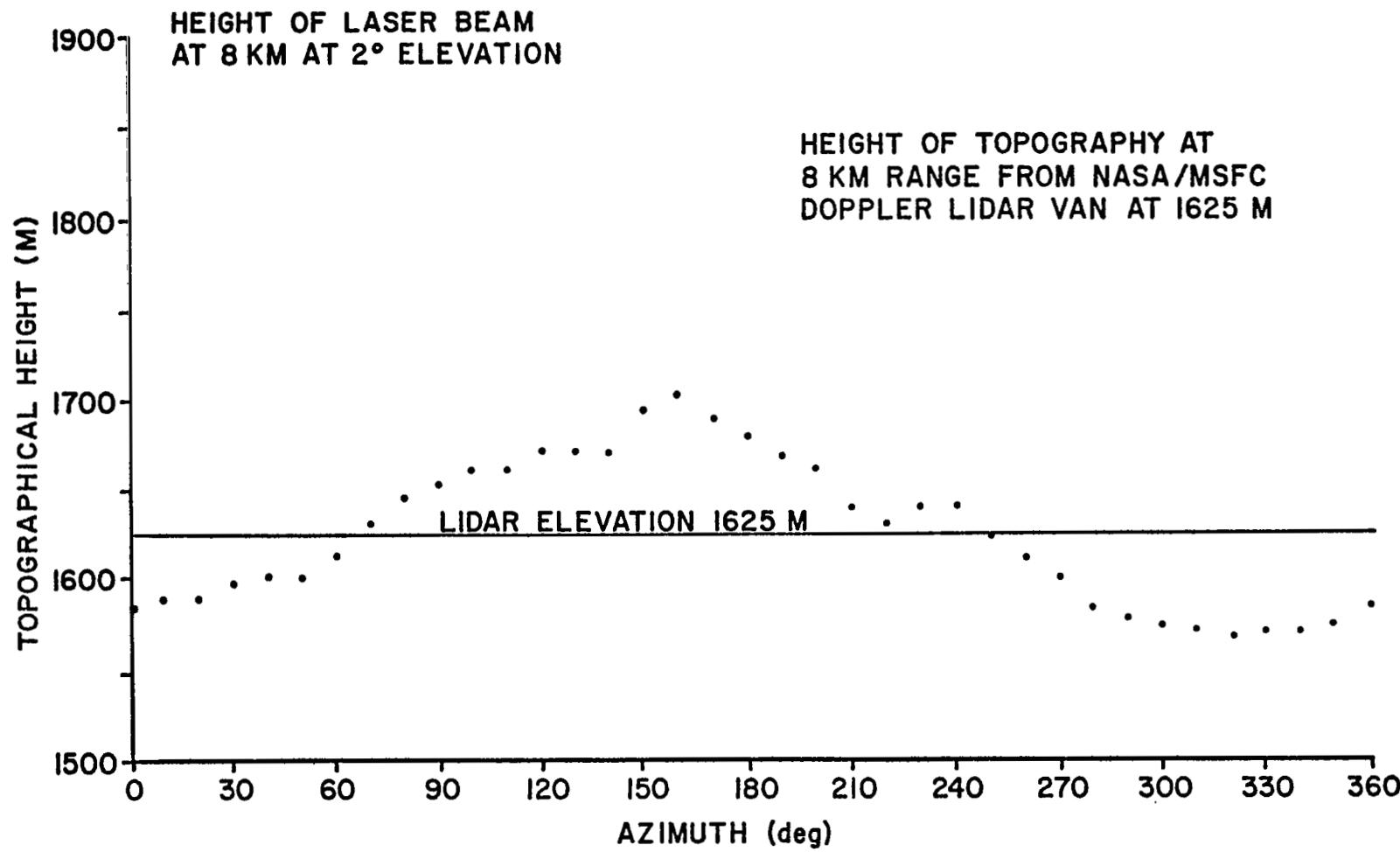


FIGURE 9. Height of the topography (meters MSL) as a function of azimuth for a range of 8 km from the NASA/MSFC's lidar van. For reference purposes, the height of the laser pulse at 8 km and 2° elevation scan angle is shown in the upper left part of the figure.

NASA/MSFC GROUND-BASED DLS

7/31/82  
 20:42:15 LT  
 PW=2 MICROSEC  
 PPS=110  
 INT= 50

V= -2.87 M/S  
 OBS PD= .45 SEC  
 R= 8030 M  
 EL= 2 AZ= 11

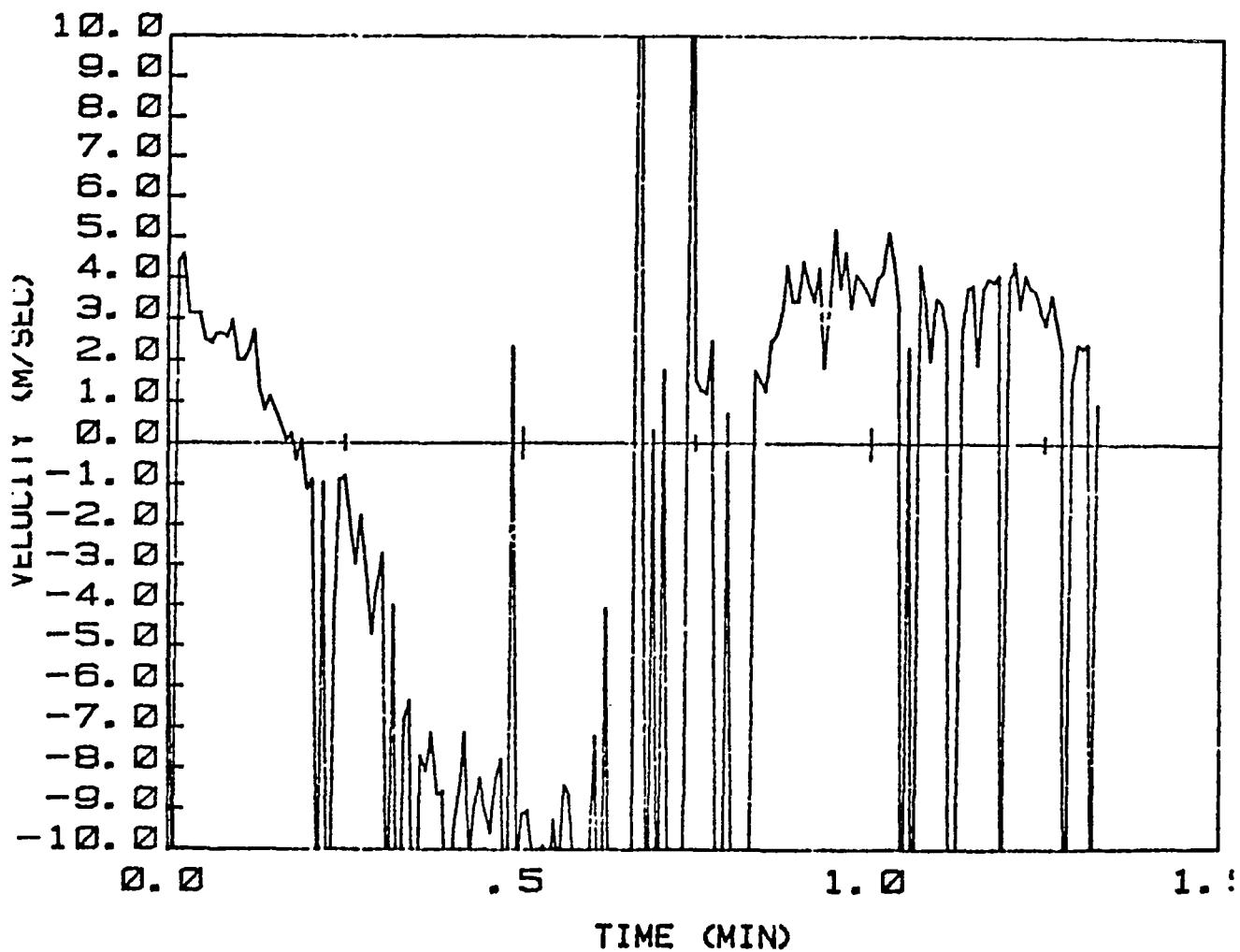


FIGURE 10. Unfiltered raw radial wind data taken at 2042 MST 31 July 1982 with the NASA/MSFC's lidar system. The  $V$  value of  $-2.87 \text{ ms}^{-1}$  indicates a rather large bias in the wind field as sampled. For homogeneous flow over flat terrain the  $V$  value would be near  $0.0 \text{ ms}^{-1}$ . As shown by the horizontal axis, a complete scan took approximately 1.2 minutes.

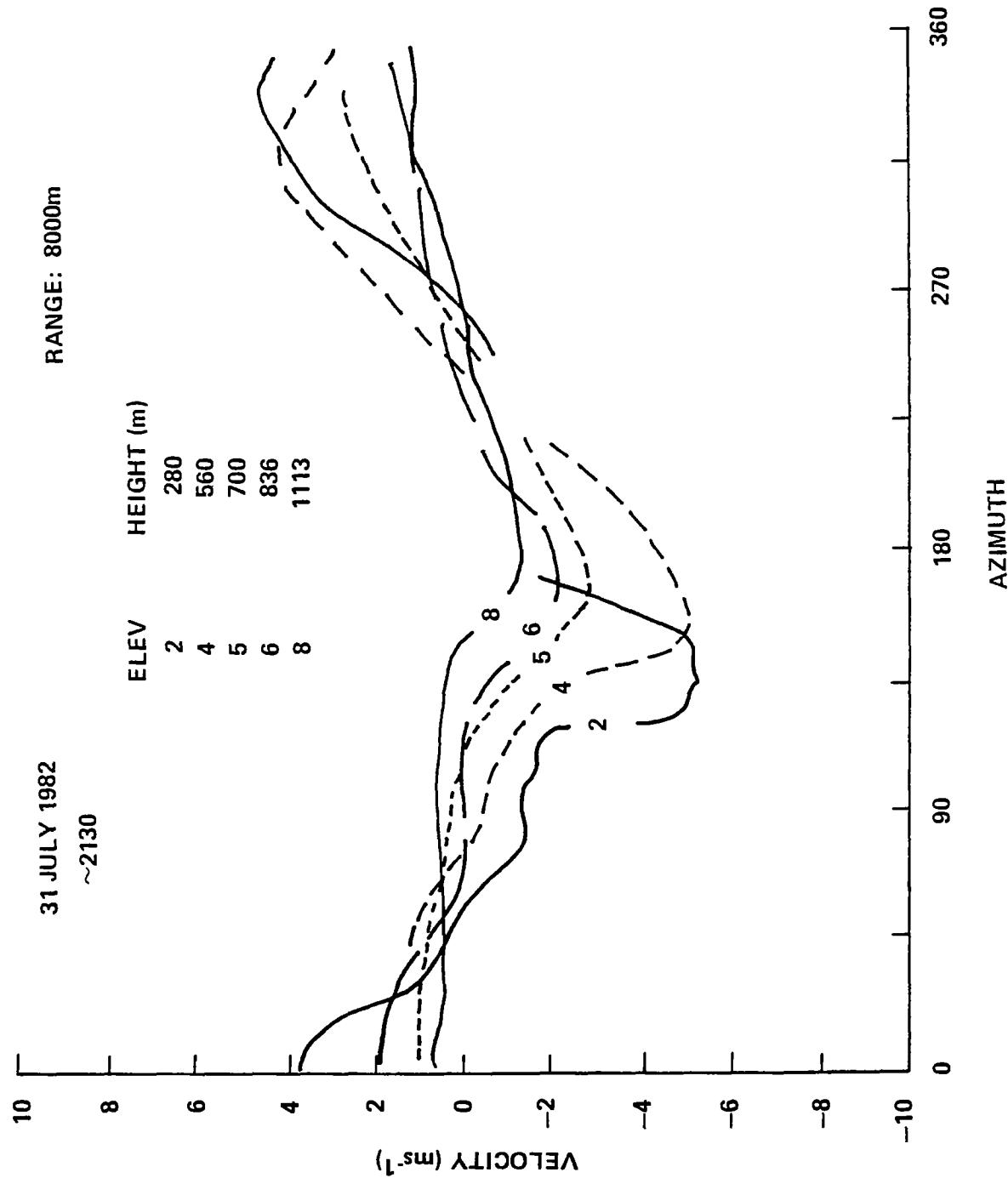


FIGURE 11. Smoothed ( $3^\circ$  filter) lidar radial wind component ( $\text{ms}^{-1}$ ) as a function of azimuth ( $0^\circ$  is looking north). The elevation/height information is for the laser pulse at 8 km range from the lidar van and is measured relative to the altitude of the lidar site (1625 m MSL). Time is in MST. Negative speeds are toward the lidar van; positive, away.

A sequence of scans at 2215 MST (Figure 12) showed a strengthening of the current to nearly  $10 \text{ ms}^{-1}$ , a widening to  $\sim 10 \text{ km}$ , but no clear sign of deepening (still  $\sim 700\text{-}800$  meters). At the  $3^\circ$  scan angle a very shallow, narrow but coherent flow was detected coming from the WSW. This feature was never seen again by the lidar but could have been a drainage flow from the mountains to the south and southwest of Denver (note the winds at the left of Figures 5b and 6a).

From the review of these lidar data spanning 2.5 hours, two major questions arose:

- 1) What could be causing the persistence of such a distinct narrow flow in an area having "subtle" terrain? and
- 2) How is the large offset in the lidar scans to be interpreted?

A close inspection of a topographic map for a range of 50 km around the lidar site disclosed not only the general south to north downslope in the near ( $<10$  km) vicinity of the airport but also a creekbed to the SSE that was directly aligned with the current detected by the lidar. Illustrated in Figure 13, the creek valley began about 50 km to the south at an elevation  $-350 \text{ m}$  above the lidar site. At a range of 30 km the width of the valley was on the order of 14 km and 150 meters deep. It was the only feature that could direct a drainage flow into the sampling domain of the lidar. If we conclude that it was the cause of the persistent channelled current detected by the Doppler lidar than it is interesting that the depth of the current is nearly 4-5 times that of the valley. Although more scans dedicated to resolving this flow would have been useful, we still have both an interesting flow visualization and a demonstration of the care that must be taken in trying to derive mean PBL wind fields from conical lidar scans.

The interpretation of single conical lidar scans is normally difficult for the PBL with its turbulent and surface related perturbations. Even where averaging several PPI's is an option, there can still be biases in the radial wind components. For example, in the case presented in Figure 12 there are two factors that must be considered in trying to understand the information illustrated in Figures 10, 11 and 12. The first factor is the diffusion or spreading out of the Cherry Creek drainage current as it passes through the 8 km radius lidar domain; the second factor is the varying sample height above the ground as the lidar beam is scanned through  $360^\circ$ . Specifically, note the  $-10 \text{ ms}^{-1}$  and  $+6 \text{ ms}^{-1}$  maximum excursions at  $3^\circ$  elevation. Since the current was first seen at 2040 MST, it had time to cross the 16 km to the northern portion of the lidar scan area. If we make an assumption that in crossing that area, the current remains unchanged, then using Figure 9, we find that looking north at  $3^\circ$  elevation is equivalent to looking south at  $4^\circ$  elevation. This would mean that the maximum speed looking north ( $3^\circ$ ) should be  $-8 \text{ ms}^{-1}$ . However, the observed speed was  $6 \text{ ms}^{-1}$ . The remaining discrepancy may be due to the current slowing down and changing shape. Once again, real time display capabilities would have led to a series of scans dedicated to obtaining more detail on the shape of the outflow current and the manner in which it evolved as it passed northward through the lidar sampling area.

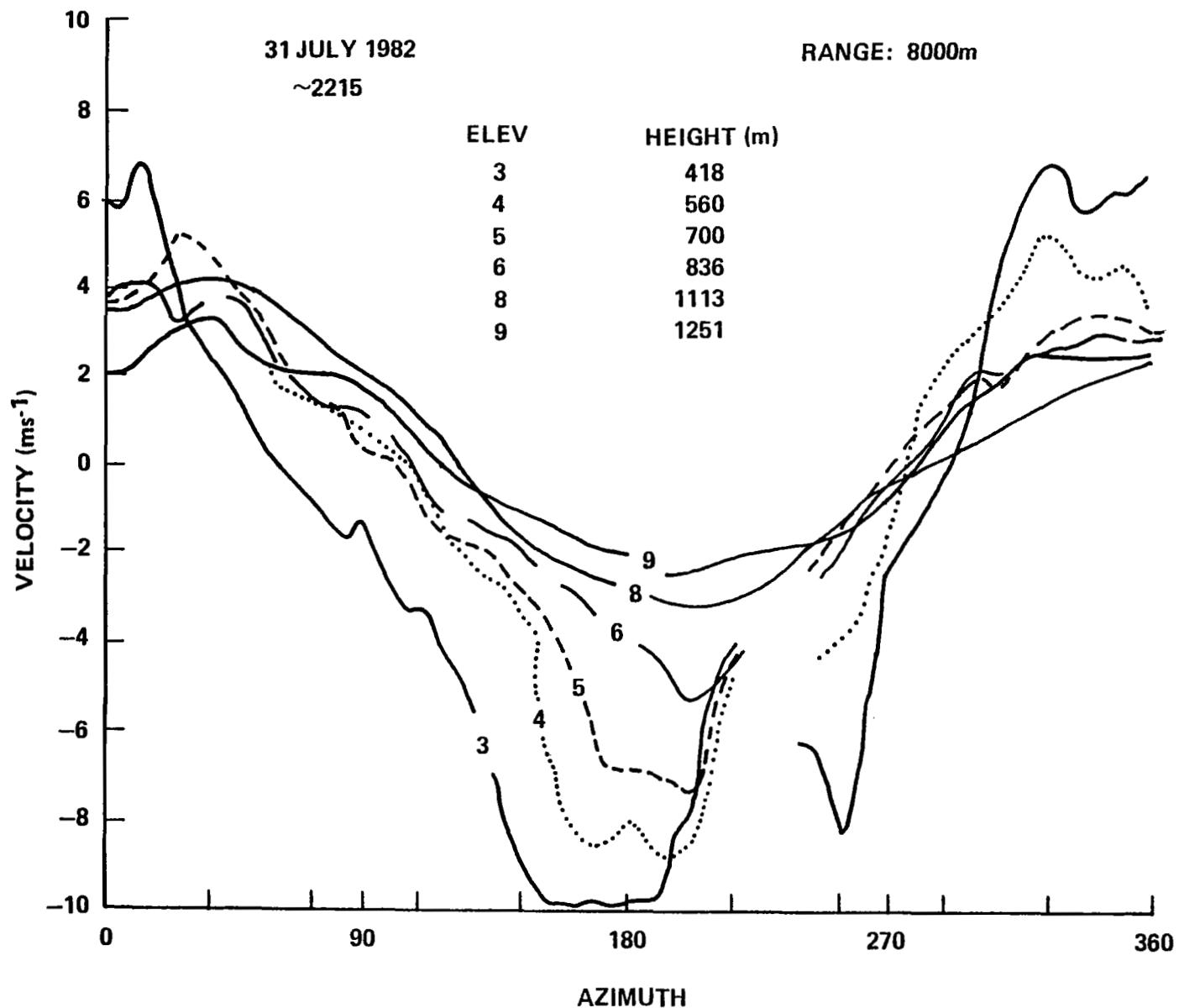


FIGURE 12. Same as in Figure 11 except for 2215 MST.

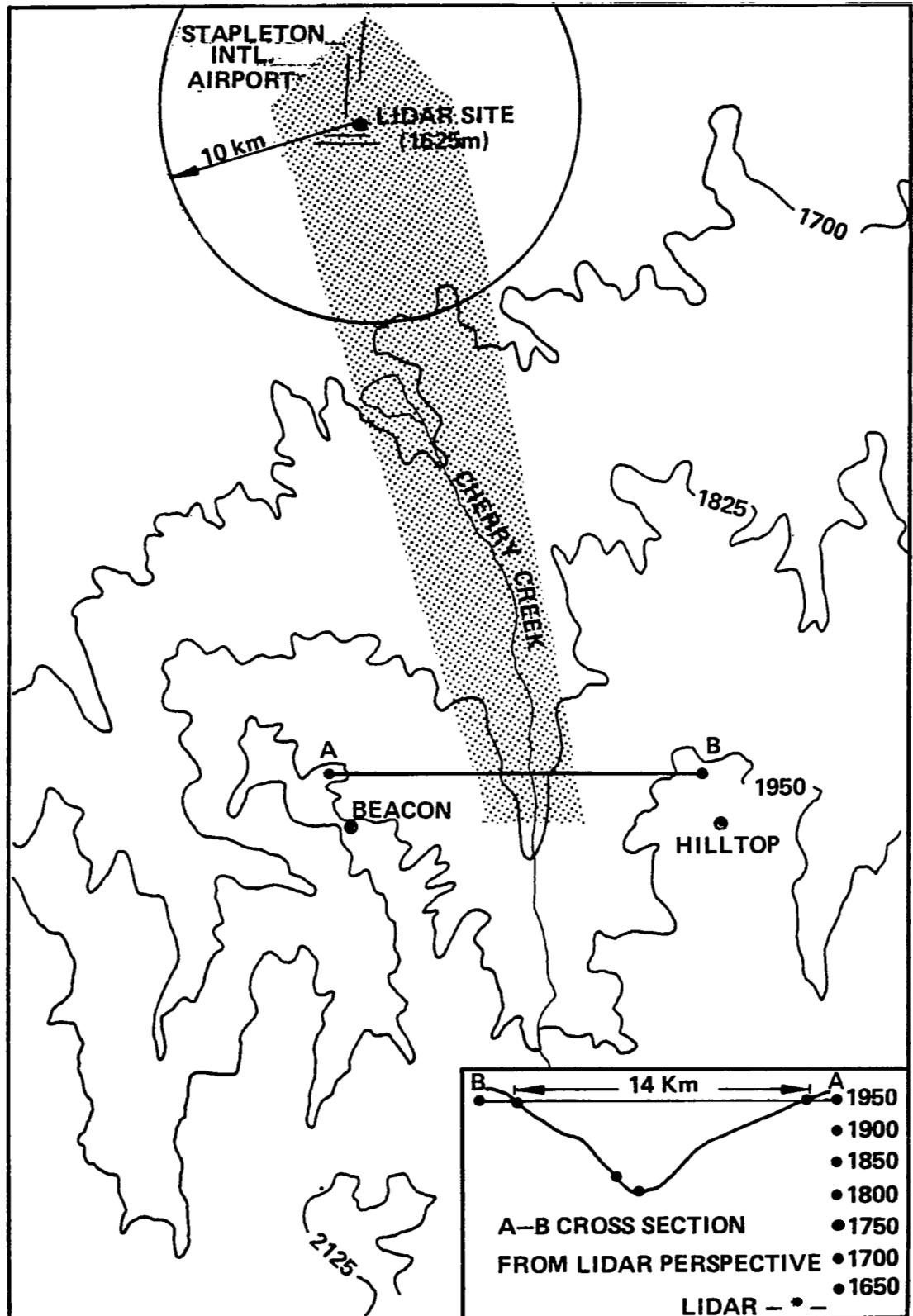


FIGURE 13. A conception of the valley drainage flow superimposed on the height (meters MSL) contours taken from a topographic map. The inset shows the height cross section between points A and B. The lidar altitude is noted by an \* near 1625 meters.

## CONCLUSIONS

This memo has reported a case of a nocturnal boundary layer flow as seen by the NASA/MSFC's pulsed CO<sub>2</sub> Doppler lidar during the 1982 JAWS experiment in Denver, Colorado. To this author's knowledge it is the first flow visualization of its kind for terrain induced drainage flows. This case is interesting in two respects 1) a unique visualization has been obtained of a channelled flow, unbounded above, that is several times (4-5) deeper than the terrain feature responsible for its organization; and 2) the care required in interpreting PPI's in the stable boundary layer in the vicinity of terrain features has been demonstrated.

Three recommendations based upon this case study are:

- 1) Real time display of the lidar information should be acquired to insure optimal research use of the DLV; and
- 2) More experiments should be performed with the DLV to develop interpretive skills with regard to PBL flows and terrained induced perturbations.
- 3) An effort should be made to combine a numerical model with observations to aid in the interpretation of the radial wind measurement provided by the lidar.

#### Acknowledgements

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16. ABSTRACT During the summer of 1982, NASA/MSFC's ground-based CO <sub>2</sub> Doppler Lidar Velocimeter (DLV) was deployed at the Denver Stapleton Airport as part of NASA's participation in the JAWS (Joint Airport Weather Studies) program. Configured to measure the radial wind component within a 10 km radius, the conically scanning lidar was used to examine the evolution of a nocturnal boundary layer under the conditions of cloud free skies and rolling terrain. A valley drainage flow was detected and a two-dimension flow visualization constructed. The depth of the gravity current was -700 meters while the depth of the creek valley was -150 meters. This deep drainage flow was detectable for distances of 30-40 km from the exit region of the valley.			
Although the sample period (2000-2300 CST) was short and only one nocturnal boundary layer case examined, the usefulness of the DLV was demonstrated as well as the care that must be exercised in interpreting lidar data taken in a stable boundary layer in the vicinity of subtle terrain features.			
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